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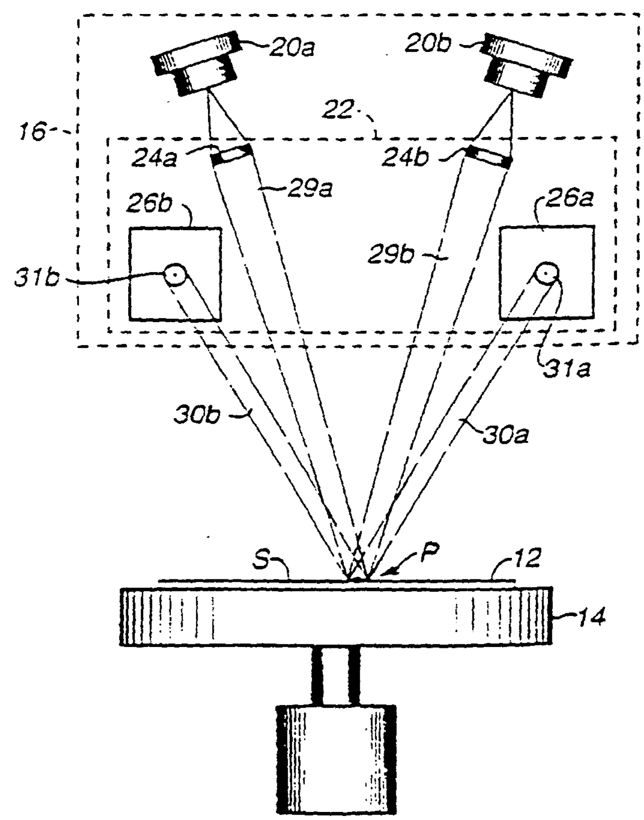
(54) Title: METHOD AND APPARATUS FOR MEASURING THE CURVATURE OF WAFERS

(57) Abstract

A method and apparatus for measuring the curvature of a wafer. The apparatus includes a laser head (16) that includes multiple laser sources (20a, 20b) that each emit a laser beam (29a, 29b), each beam having a different wavelength. A CPU selects one of the sources to emit a beam. The beam is directed through a lens (24) within the laser head and onto a surface of a wafer. The beam is reflected from the surface of the wafer and detected by a detector. The present invention includes a motor to cause relative motion between the laser head and the wafer such that the beam scans across the surface of the wafer, relaying data to the detector and the CPU. The CPU calculates the curvature of the wafer surface using the scanned data. The CPU selects a different laser source to direct a beam having a different wavelength at the wafer surface to avoid destructive interference that may occur with previously-used wavelengths. Other embodiments include the laser sources within a carousel apparatus, and the addition of a beam splitter to transmit and reflect selected beams onto the wafer surface.



METHOD AND APPARATUS FOR MEASURING THE CURVATURE OF WAFERS

Description

Technical Field

This invention relates to semiconductor manufacturing, and more particularly to measuring surface curvature of semiconductor wafers.

Background Art

Integrated circuits are formed on semiconductor wafer substrates by a number of processing steps. These steps include deposition, etching, implantation, doping, and other semiconductor processing steps well known to those skilled in the art.

Thin films are typically formed on wafer surfaces by a deposition process. The thickness of such films usually ranges from about a few hundred angstroms to several micrometers. Often, three or more film layers are formed on the surface of a single semiconductor wafer.

In the art of fabricating semiconductor wafers, it is of known importance to minimize or control stresses in surface films. High surface stresses can cause, for example, silicide lifting, the formation of voids or crack and other conditions that adversely affect semiconductor devices (i.e. chips) which are fabricated on the wafers. In practice, surface stresses become more problematical as the level of circuit integration increases, and are especially troublesome when fabricating large scale integration (LSI), very large scale integration (VLSI), and ultra large scale integration (ULSI) semiconductor devices.

The stress in the surface film of a semiconductor wafer can be either compressive or tensile. Assuming the film is on top of the wafer, a compressive stress in a surface film will cause a wafer to slightly bow in a concave direction, while a tensile stress in a surface film will cause a wafer to slightly bow in a concave direction. Therefore, both compressive and tensile stresses cause the surface of the semiconductor wafer to deviate from exact planarity. The extent of the deviation from planarity can be expressed in terms of the radius of curvature of

a wafer surface. In general, the greater the magnitude of surface stress, the smaller the radius of curvature.

Because of the problems that can be caused by stresses in surface films on semiconductor wafers, it is highly desirable to be able to measure such stresses. The measurements can be used, for example, to identify wafers that are likely to provide low yields of semiconductor devices or which might produce devices prone to early failure. In normal practice, stresses in surface films are not measured directly but, instead, are inferred from measurements of the radius of curvature of the surface of interest.

A system for measuring the curvature of a workpiece, such as a wafer, is described in U.S. Patent No. 5,270,560 of David Cheng, entitled "Method and Apparatus for Measuring Workpiece Surface Topography." This system reflects a guided beam of radiant energy, such as one generated by a laser, from a surface film of a workpiece. A detector detects a portion of the reflected beam; as the wafer or laser is moved, the deviation of the beam from a point at the detector is recorded and analyzed to detect curvature of the surface.

A problem encountered with this system is that the amplitude of the beam of energy reflected from the surface film of the workpiece can be reduced due to destructive interference. The interference is caused by reflection from the surface film on the workpiece, which includes an upper surface boundary and a lower surface boundary. A beam of light is partially reflected and partially transmitted through the upper film boundary. The transmitted portion of the beam is reflected by the lower film boundary and interferes with the first reflected portion of the beam due to well-known optical interference principles. The thickness of the surface film can cause the second reflected portion of the beam to be out-of-phase with the first reflected portion, and destructive interference in the entire beam can result. Destructive interference may weaken or almost completely cancel the amplitude of the reflected beam of energy, causing difficulties in detecting the reflected beam and resulting in errors in the curvature testing process.

In U.S. Patent 5,134,303, by Blech et al., a dual frequency laser apparatus for measuring stress in a thin film is disclosed. A laser beam composed of two different wavelengths is directed onto a surface with a thin film and reflected to a detector. If one of the wavelengths permits destructive interference to occur in the reflected beam, the other transmitted wavelength may not, and the reflected beam can be detected. Two separate laser beams, each of a distinct wavelength, are combined into the dual-wavelength beam by a beam splitter to accomplish this goal.

A problem with the prior art dual frequency laser apparatus is that a beam of multiple wavelengths is directed at a thin film surface. Both laser sources are required to concurrently project energy in a beam of multiple wavelengths, requiring both lasers to be concurrently powered and maintained. A waste of energy is thus evident.

What is needed is an apparatus and method that will reduce the problem of destructive interference that occur in surface film curvature measurement and also reduce the inefficiency of using combined, multiple-frequency energy sources to measure thin films.

Disclosure of the Invention

The present invention addresses the problems of the prior art by providing a method and apparatus to measure the curvature of a workpiece by selecting one of several light sources to emit a laser beam. One source is selected at any one time to create the beam. The wavelengths of the beams are different so that at least one of the beams is not significantly reduced in amplitude by destructive interference when reflected from a thin film on the workpiece surface.

The apparatus includes a laser head that includes multiple sources of electromagnetic radiation that emit the radiation in a beam, such as a laser beam. Each beam has a different wavelength. A CPU or similar controller apparatus selects one of the sources to emit a beam. The beam is directed through a lens within the laser head and onto a surface of a workpiece, such as a wafer. The beam is reflected from the surface of the workpiece and detected by a detector. The CPU is connected to the detector and receives information from the detector relating to the position of the beam on the surface of the workpiece. The present invention preferably includes a motor to cause relative motion between the laser head and the workpiece such that the beam is scanned across the surface of the workpiece, relaying information to the detector and the CPU. The beam can be moved across the workpiece, or the workpiece can be translated while the beam remains stationary to scan the beam across the surface.

The CPU calculates the curvature of the workpiece surface using the scanned data received from the detector. If the data received from the detector is judged inaccurate or unreliable by the CPU, the CPU selects a different laser source to direct a beam having a different frequency at the wafer surface to avoid the destructive interference that occurred using the previous wavelength.

The present invention preferably includes multiple mirrors that reflect a beam to the detector, each mirror corresponding to a laser source. In the preferred embodiment, a laser source and corresponding lens is incorporated within a laser "pen" structure that allows the lens to be moved to focus the laser beam. In alternate embodiments, the laser sources are incorporated within a carousel that rotates a specific laser source into position to direct a beam at the workpiece surface. In another embodiment, a polarizing beam splitter is preferably positioned to transmit a beam from one laser source and reflect a different beam from a different laser source onto the workpiece surface; the apparatus preferably uses a single mirror to direct the beam to the detector. In yet another embodiment, the CPU selects one laser source at a time to scan first a blank wafer and then to secondly scan a wafer deposited with a thin film in order to eliminate inherent wafer curvature effects in the curvature calculations.

The present invention has the advantage of selecting one source at a time to direct a beam at a workpiece surface to measure curvature, thereby reducing the continuous, concurrent use of all laser sources, and, in many cases, eliminating the use of one or more sources.

This and other advantages of the present invention will become apparent to those skilled in the art after reading the following descriptions and studying the various figures of the drawings.

Brief Description of the Drawings

FIGURE 1 is a side elevational view of an apparatus to measure curvature of the present invention;

FIGURE 2 is a front elevational view taken along line 2-2 of the apparatus shown in Figure 1;

FIGURE 3 is a side view of laser beams of two different wavelengths reflected from a thin film on a wafer surface;

FIGURE 4 is a side view of laser beams reflected from a thin film having a different thickness from the thin film of Figure 3;

FIGURE 5 is a front elevational view of a preferred implementation of a laser head of the present invention;

FIGURE 6 is a side elevational view taken along line 6-6 of the laser head shown in Figure 5;

FIGURE 7 is a cross section of a preferred laser "pen" used in the present invention;

FIGURE 8a is a block diagram of the control system used in the present invention;

FIGURE 8b is an overhead view of a scan line formed on a wafer surface by the laser head of the present invention;

FIGURE 9a is a flow diagram of a preferred method of the present invention;

FIGURE 9b is a flow diagram of an alternate preferred method of the present invention;

FIGURE 10 is a schematic diagram of a first alternate embodiment of the apparatus to measure curvature;

FIGURE 11 is a detailed view of a laser carousel used in the apparatus of Figure 10 as seen along line 11-11; and

FIGURE 12 is a schematic diagram of a second alternate embodiment of the apparatus to measure curvature.

Best Modes for Carrying out the Invention

Figure 1 is a side elevational view of a preferred embodiment of an apparatus 10 for measuring the curvature of a wafer in accordance with the present invention. A wafer 12 to be measured for curvature rests on a pedestal 14 and includes an upper surface S. While the present invention will be discussed in terms of measuring the curvature of a semiconductor wafer, such as wafer 12, it should be understood that this invention can be used to non-destructively measure the surface topography of a variety of workpieces, including hard disk platters, optical blanks, etc. As used herein, "topography" refers to any description of a surface of a workpiece, such as curvature, contours, etc.

Apparatus 10 includes a multiple frequency laser head 16 and a beam detector 18. Laser head 16 includes laser sources 20 and a beam directing apparatus 22.

Laser sources 20 are multiple laser sources, each preferably a Class IIIb laser product certified by the Federal Food and Drug Administration under FDA 27 CFR 1040, 10(f)(5)(ii). In the described embodiment, there are two laser sources, 20a and 20b that preferably operate at wavelengths of approximately 810-830 nm and 670-750 nm, respectively (see also Figure 2 for position of laser sources). A typical maximum power output of the laser sources 20a and 20b is less than 2mW.

Beam directing apparatus 22 preferably includes a lens 24 and a mirror 26. Lens 24 is preferably a converging lens that has a focal length which allows a beam 28 produced by a laser source 20 to form a beam spot on wafer surface S of wafer 12 and beam detector 18. The beam spot formed on the wafer surface preferably should be about 3mm in diameter, and the beam spot formed on the beam detector should be about 20-50 mm in diameter. Mirror 26 is preferably a front silvered mirror that directs the beam to beam detector 18 after it has been reflected from surface S. A laser source 20a and 20b forms an incident beam 29 which impinges upon the surface S of the wafer 12. The surface S of the wafer reflects a portion of the incident beam 29 as a reflected beam 30. The reflected beam 30 impinges upon the reflective surface of mirror 26 and is reflected towards the beam detector 18 as a directed beam 31. Therefore, beam 28 comprises the sum of beams 29, 30, and 31. The effective reflected beam path length comprising beams 30 and 31 is about 300 mm.

Figure 2 is a side elevational view of the laser head 16 and wafer 12 taken along line 2-2 of Figure 1. Laser sources 20a and 20b are positioned on opposite sides from a point P on the wafer surface. Each laser source is oriented so that an incident beam 29a or 29b will be directed at the point P. Beams 30a and 30b are reflected from the surface of the wafer, and beams 31a and 31b are directed at the beam detector 18 (out of the plane of the drawing). Beam 28a is thus composed of incident beam 29a, reflected beam 30a, and directed beam 31a. Beam 28b is correspondingly composed of incident beam 29b, reflected beam 30b, and directed beam 31b.

Figure 3 is a schematic diagram illustrating the reflection of incident beams 29a and 29b from the wafer surface S and a thin film 34. Figure 3 shows a side view of wafer 12 that has been coated with a thin film 34 having a thickness T_1 and an upper surface U. Upper surface S of the wafer supports thin film 34. The

incident laser beam 29a from laser source 20a includes wave fronts 36 and has a first wavelength. Incident beam 29a is directed at the wafer at a point P. A portion 38a of beam 29a is reflected from the upper surface U of the thin film and a portion 40a continues to transmit through the thin film 34. Portion 40a impinges on the boundary of wafer surface S and thin film 34 and a portion 42a is reflected from surface S. Portion 42a emerges from thin film 34 (after another small amount of reflection again at surface U) proximate to reflected portion 38a. Reflected portions 38a and 42a both originated from the same laser source 20a and are coherent; a phase difference exists between the two portions due to the different lengths traveled, different mediums traveled through, and different interfaces encountered. Interference will thus occur between portions 38a and 42a; the amount and type (destructive or constructive) of interference depends on the amount of phase difference between the two portions. Portions 38a and 42a in Figure 3 are almost 180 degrees out of phase, and thus almost completely cancel each other out. The small amplitude of resulting reflected beam 30a shows this destructive interference; reflected beam 30a is difficult to detect in detector 18.

Figure 3 also shows incident beam 29b directed at wafer 12 covered with thin film 34 having the same thickness T_1. Beam 29b has a distinctly different wavelength than incident beam 29a. Reflected portions 38b and 42b constructively interfere, resulting in a larger amplitude for reflected beam 30b than for beam 30a. Incident beam 29b thus has a wavelength that will allow beam detector 18 to detect a beam reflected from a thin film of thickness of T_1.

Figure 4 is a schematic diagram illustrating the reflection of incident beams 29a and 29b from a different thin film. Thin film 34 has a thickness T_2, which is different from thin film thickness T_1 shown in Figure 3. Here, incident beam 29a has a portion 38a reflected from surface F of thin film 34 and a portion 42a reflected from the surface S of wafer 12. Portions 38a and 42a constructively interfere to produce a reflected beam 30a with about the same amplitude as beam 29a. In contrast, incident beam 29b has the same wavelength as beam 29b in Figure 3, but produces two reflected portions 38b and 42b that destructively interfere and cause a beam 30b with smaller amplitude to be reflected. It is thus advantageous to use both beams 29a and 29b with different wavelengths to determine which wavelength produces a reflected beam 30 with the highest amplitude.

Figure 5 is a front view of a preferred multi-frequency laser head 16 of apparatus 10 shown in Figures 1 and 2. Laser sources 20a and 20b and lens 24a and 24b are shown included within laser "pens" 44a and 44b (detailed with reference to Figure 7). Knobs 46a and 46b can be adjusted by the operator to

tighten laser pens 44a and 44b and fix the focus of the projected laser beams. Laser beams are directed through opening 48 provided in the bottom base of a frame 50 supporting laser pens 44a and 44b and mirrors 26a and 26b. The beam is reflected from a wafer surface below laser head 16 and is reflected back to mirrors 26a and 26b. Mirrors 26a and 26b are positioned below laser pens 44a and 44b. In the preferred embodiment, wafer 12 is positioned about 2-4 inches below laser pens 44a and 44b.

Figure 6 is a side elevational view of the laser head taken along line 6-6 of Figure 5. Adjustment screws 52 are positioned behind mirrors 26a and 26b. Screws 52 can be moved in towards mirrors 26a and 26b or out away from the mirrors to adjust the angle of mirrors 26a and 26b. The mirrors are adjusted to align the directed beam 31 with the beam detector 18, as shown in Figure 1.

Figure 7 is a cross-sectional view of a preferred embodiment of a laser pen 44 shown in Figures 5 and 6. Diode laser element 54 is positioned in a laser source barrel 20 of laser pen 44 at a fixed distance d from the surface 55 of the laser pen. The barrel 20 is provided with a pair of splits S. Beam 29 emanates from a PN junction of the diode laser element 54 and is focused by a lens L of the laser pen. Lens L is supported by a barrel 56 that has screw threads 57 which can engage threads 58 on laser source barrel 20. The focus of the pen 44 can be adjusted by rotating the barrel 56 to cause the lens L to move forward or away from the diode laser 54. Knobs 46 (shown in Figures 5 and 6) are tightened by an operator to clamp barrel 20 to barrel 56 by squeezing the barrel 20 such that it compresses due to slits S and grips the inner barrel 56.

Figure 8a is a block diagram 60 showing a preferred control system for the present invention. A central processing unit (CPU) 62 is connected to a motor control circuit 64, which controls the movement of laser head 16. CPU 62 is preferably a microprocessor, such as an Intel 80386 of an IBM-compatible personal computer. Laser head 16 is preferably directed to translate within the x-y plane so that laser sources 20a and 20b can scan a beam 29a and 29b onto wafer 12 while wafer support 14 remains stationary. Such motor control circuitry and translation apparatus are discussed in co-pending patent application 07/876,576.

Alternatively, CPU 62 and motor control circuit 64 can direct wafer support 14 to translate in the x-y plane (shown by the broken line) while laser head 16 remains stationary. Wafer support 14 is moved using a similar well known apparatus to the embodiment described above. Wafer support 14 can also be

rotated by a spindle and stepper motor within the x-y plane to provide additional translation.

Laser head 16 directs an incident beam 29 onto the wafer 12 and reflects the returning reflected beam 30 at detector 18 as directed beam 31. Detector 18 reads the position of the beam and relays the information to CPU 62. As incident beam 29 is scanned across the surface of the wafer, CPU 62 thus receives the data describing the topography of the wafer surface. CPU 62 then processes the received data to calculate a curvature measurement for the scanned area on wafer 12. Multiple scanned areas can be implemented to provide CPU 62 with additional data to calculate a more accurate curvature of the wafer surface. A method for both detecting a beam, scanning a beam across a wafer, and calculating a curvature measurement from scanned data is described in copending patent application 07/876,576 by D. Cheng, assigned to the same assignee and incorporated by reference herein.

Figure 8b is a top view of wafer 12 and a scanning path 66 for beam 29. Relative motion in the x-y plane between laser head 16 and wafer support 14 can be provided using well known components as described with reference to Figure 8a. Incident beam 29 can follow a scan line 66 across the wafer surface. The scan line 66 is, essentially, a series of points P linearly arranged on the surface of wafer 12. As the beam 29 is scanning, the position of reflected beam 30 at various points P along scan line 66 can be detected by detector 18 and stored by CPU 62 as data to calculate surface curvature. For example, the CPU can sample points along a scan line 66 at a predetermined sampling rate to provide a set of data. Beam 29 can be directed to follow a different scan line 66 to provide another set of data describing the curvature of the wafer surface by rotating the support 14 or the laser head 16.

The scan of beam 29 can follow a linear scan line 66 as shown in Figure 8b or other patterns. If wafer support 14 is coupled to a spindle and motor for rotation, beam 29 can follow circular scan lines across the surface of wafer 12.

Figure 9a is a flow diagram 70 showing a preferred method of the present invention to measure the curvature of a workpiece. The process begins at step 72, and, at step 74, a first laser source 20a is selected by CPU 62 to transmit a first beam 29a of a particular wavelength. In step 76, the curvature test described above is implemented. The CPU calculates a curvature measurement from data obtained by scanning the first beam across the wafer surface.

The CPU determines in step 78 whether the first beam 29a has provided valid data, i.e. if the beam has suffered destructive interference or not. The CPU can compare the data received by detector 18 to a predetermined minimum threshold amplitude to determine if the data is above the minimum and within a predetermined operating range. If the data is determined to be valid, then the process is complete at step 80. If the data amplitude is determined to be below the predetermined minimum level (the first beam suffered destructive interference), then the process continues to step 82. In step 82, the CPU selects a second laser source 20b to transmit a beam 29b having a different wavelength than the first beam selected. In step 84, the curvature measurement test is implemented with the second beam. The CPU calculates the curvature of the wafer surface using the second set of data and the process is complete as indicated in step 180.

If further laser sources providing laser beams of differing wavelengths are used in other embodiments, the CPU can continue to select other laser sources if the data resulting from the second is below an accuracy threshold.

Figure 9b is a flow diagram 86 of an alternate method to measure the curvature of a workpiece using the present invention. The process begins at step 88 and, in a step 90, a blank wafer is scanned with a first beam from a first laser source. The blank wafer does not have a thin film deposited on its surface. In a step 92, the CPU selects a second laser source and scans the blank wafer with a second beam having a different wavelength than the first beam. In step 94, a thin film is deposited on the wafer using well known techniques. In step 96, the deposited wafer is scanned again by the first beam from the first laser source. In step 98, the deposited wafer is scanned by the second beam from the second laser source. In step 100, the CPU uses the entire set of data from the four scans to calculate the curvature of the wafer. The CPU can subtract the sets of data describing the blank wafer from the sets of data describing the deposited wafer to eliminate the effects of the intrinsic curvature of the surface that existed before deposition. After the curvature of the wafer surface is calculated, the process is complete as indicated in step 102.

Figure 10 is a front elevational view of an alternate embodiment of the present invention. Apparatus 10' includes a laser head 16', a detector 18, a motor 106, and a detector 18. Laser head 16' includes a carousel 104 that houses two laser sources 20a and 20b. Each of the laser sources 20a and 20b can direct a laser beam having a different wavelength from the other laser source. The carousel can preferably be rotated about central axis A by motor 106, which is coupled to carousel 104 by a spindle 108. Laser sources 20a and 20b may be alternately

positioned above lens 24 to project a beam 29a or 29b onto wafer 12. Motor 106 is preferably controlled by CPU 62, which can select a laser source 20a or 20b by rotating carousel 104. Detector 18 and mirror 26 are similar to equivalent components described with reference to Figures 1 and 2. This embodiment requires only one lens and one mirror, and thus reduces the number of components from the apparatus shown in Figures 1 and 2. However, the carousel 104 is more difficult to construct and implement than the apparatus of Figures 1 and 2. The remainder of the apparatus 10' operates in a manner similar to apparatus 10 described previously.

Figure 11 is a bottom view of carousel 104 taken along line 11-11 of Figure 10. Laser sources 20a and 20b are preferably positioned along the circumference of carousel 104 so that one source 20a or 20b may be positioned above lens 24 (Figure 10) at one time by rotating carousel 104 about axis A by an angle q. If more than two laser sources 20a and 20b are being used, the additional sources can be positioned similarly along the edge of carousel 104 and accessed by rotating the carousel 104 by an appropriate angle.

Figure 12 is a front elevational view of a second alternate embodiment of the present invention. Apparatus 10" includes a laser head 16" and a detector 18. Laser head 16" includes laser sources 20a and 20b, lens 24a and 24b, mirror 26, and beam splitter 108. Laser sources 20a and 20b, lens 24a and 24b, and mirror 26 are similar to those components described with reference to Figures 1 and 2. Beam splitter 108 is preferably a polarizing beam splitter that is positioned to intercept beams 29a and 29b projected from laser sources 20a and 20b. Polarizing beam splitters suitable for use with the present invention can be obtained from Mellis Griot. Laser source 20a preferably projects a laser beam having S-polarization, i.e., the electric field of beam 29a is vibrating in a direction so that the beam will be transmitted entirely through beam splitter 108. Laser source 20b preferably projects a laser beam having P-polarization, i.e., the electric field of beam 29b is vibrating in a direction at right angles to the vibration of the electric field of beam 29a so that beam 29b is entirely reflected by beam splitter 108. Laser sources 20a and 20b are preferably positioned so that beam 29a impinges on surface B from one side, and beam 29b impinges on surface B from the other side. As shown in Figure 12, beam 29a is transmitted through the beam splitter 108 with no reflection from surface B. Beam 29b, however, is reflected from surface B to impinge on the same point P on wafer surface S. Thus, in this embodiment, only one mirror 26 is required, since beam splitter B directs the beams accordingly to impinge on the single mirror. One beam 29a or 29b is projected through beam splitter 108 at one

time, followed by the projection of the other beam. In an alternate embodiment, a non-polarizing beam splitter is used. When using a non-polarizing beam splitter, the beams 29a and 29b do not have to be S- and P-polarized as described above. However, the beams lose some intensity when directed through the non-polarizing beam splitter. Again, the remainder of apparatus 10" operates similarly to apparatus 10' and 10 described previously.

While this invention has been described in terms of several preferred embodiments, it is contemplated that alterations, modifications and permutations thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. It is intended that the claims include all such alterations, modifications and permutations as fall within the spirit and scope of the present invention.

Claims

1. A multi-frequency laser head (16) comprising:

a plurality of sources of electromagnetic radiation (20a,20b);

means for selecting one of said plurality of sources to form a selected beam at substantially a single wavelength; and

means (24) for directing said beam to a surface of a workpiece.

2. A multi-frequency laser head as recited in claim 1 wherein said plurality of sources include a plurality of laser sources.

3. A multi-frequency laser head as recited in claim 1 wherein each of said laser sources forms a beam having a distinct wavelength.

4. A multi-frequency laser head as recited in claim 3 wherein two of said laser sources can form laser beams having wavelengths within the ranges of about 810-830 nm and about 670-750 nm, respectively.

5. A multi-frequency laser head as recited in claim 2 wherein each of said laser sources includes a converging lens means.

6. A multi-frequency laser head as recited in claim 3 wherein said laser sources are positioned inside a rotatable carousel.

7. A multi-frequency laser head as recited in claim 3 wherein said means for selecting includes a digital controller means coupled to said laser sources.

8. A multi-frequency laser head as recited in claim 2 wherein said means for directing said beam includes lens means.

9. A multi-frequency laser head as recited in claim 5 wherein each of said laser sources further include means for adjusting the focus of said converging lens means.

10. A multi-frequency laser head as recited in claim 8 wherein said means for directing said beam includes reflecting means.

11. A multi-frequency laser head as recited in claim 10 wherein said reflecting means includes a plurality of mirror means, each of said mirror means corresponding to one of said laser sources.

12. A multi-frequency laser head as recited in claim 10 wherein said means for directing said beam includes beam splitter means operative to reflect at least one of said beams onto said surface and transmit at least one of said beams onto said surface.

13. An apparatus for measuring the curvature of a workpiece surface comprising:

a plurality of sources of electromagnetic radiation (20a,20b);

means for selecting only one of said plurality of sources to form a beam;

means (24) for directing said beam to a surface of a workpiece;

means for imparting relative motion between said beam and said workpiece such that said beam scans at least a portion of said workpiece;

means (18) for detecting a reflected portion of said beam as said beam scans said selected portion of said workpiece; and

means for determining curvature of said workpiece based, at least in part, from said means for detecting a reflected portion of said beam.

14. An apparatus as recited in claim 13 wherein said plurality of sources includes a plurality of laser sources, each laser source providing a laser beam having a distinct wavelength.

15. An apparatus as recited in claim 13 wherein said means for selecting one of said plurality of sources includes controller means coupled to said sources.

16. An apparatus as recited in claim 15 wherein said means for directing said beam includes lens means.

17. An apparatus as recited in claim 16 wherein said means for directing said beam includes means for reflecting a portion of said beam to said means for detecting.

18. An apparatus as recited in claim 17 wherein said means for reflecting includes a plurality of mirrors.

19. An apparatus as recited in claim 16 wherein said means for imparting relative motion between said beam and said workpiece includes motor means coupled to said plurality of sources and said means for directing said beam.

20. An apparatus as recited in claim 16 wherein said means for imparting relative motion between said beam and said workpiece includes motor means coupled to said wafer.

21. An apparatus as recited in claim 20 wherein said means for determining curvature of said workpiece includes digital computation means.

22. A method for measuring the curvature of a workpiece surface comprising:

a) directing a beam of electromagnetic radiation having a first wavelength at a workpiece surface;

b) scanning said beam across at least a portion of said workpiece surface;

c) detecting a reflected portion of said beam of radiant energy;

d) measuring the curvature of said workpiece surface utilizing said detected portion of said beam;

e) selecting a beam of radiant energy having a second wavelength;

f) repeating steps a) through d).

23. A method as recited in claim 22 wherein said step of directing a beam includes directing a laser beam at a wafer surface.

24. A method as recited in claim 23 wherein said step of directing a laser beam includes directing a laser beam having a wavelength selected from the group of ranges of about 810 nm to 830 nm and about 670 nm to 750 nm.

25. A method as recited in claim 24 wherein said step of directing a beam includes directing said beam through beam splitting means.

26. A method as recited in claim 25 wherein said beam splitting means is a polarizing beam splitting means.

27. A method as recited in claim 23 wherein said surface remains substantially stationary during said scanning step and said beam is caused to move across said surface.

28. A method as recited in claim 23 wherein said beam remains substantially stationary during said scanning step and said beam is caused to move across said surface.

29. A method as recited in claim 22 wherein said step of detecting a reflected portion of said beam is accomplished at a predetermined times during said scanning step.

30. A method as recited in claim 23 further comprising a step of reflecting said reflected portion of said beam before said step of detecting said reflected portion.

31. A method as recited in claim 30 wherein said step of selecting a beam having a second wavelength includes rotating a carousel means from which said beams originate.

32. A method for measuring the curvature of a workpiece surface comprising:

a) scanning a beam of electromagnetic radiation having a first wavelength across a portion of a workpiece surface to provide a set of data describing said workpiece surface;

b) scanning a beam of electromagnetic radiation having a second wavelength across a portion of a workpiece surface to provide a set of data describing said workpiece surface;

c) depositing a thin film on said workpiece surface;

d) scanning a beam of electromagnetic radiation having said first wavelength across a portion of said deposited wafer surface to provide a set of data describing said deposited workpiece surface;

e) scanning a beam of electromagnetic radiation having said second wavelength across a portion of said deposited wafer surface to provide a set of data describing said deposited workpiece surface;

f) utilizing said sets of data to calculate the curvature of said workpiece surface.

33. A method as recited in claim 32 wherein said workpiece is a wafer.

34. A method as recited in claim 33 wherein said step of utilizing said data includes subtracting values of said sets of data describing said blank wafer surface from values of said sets of data describing said deposited wafer surface.

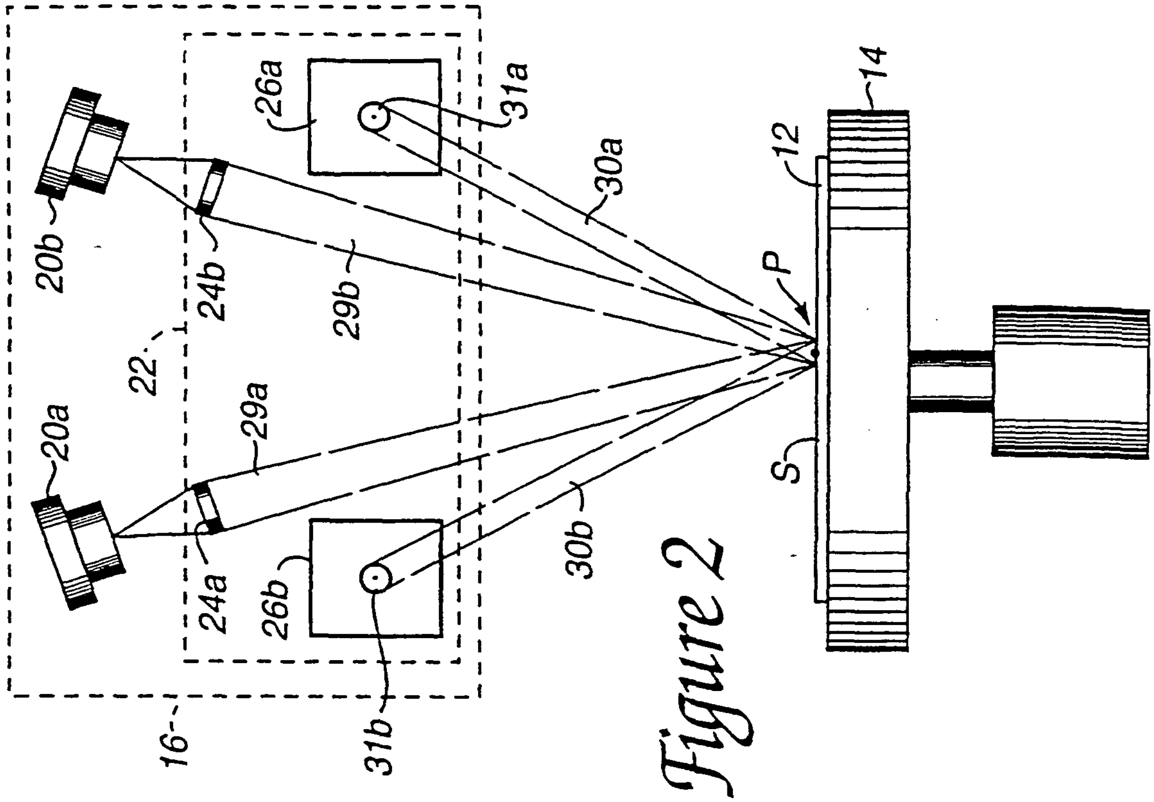


Figure 2

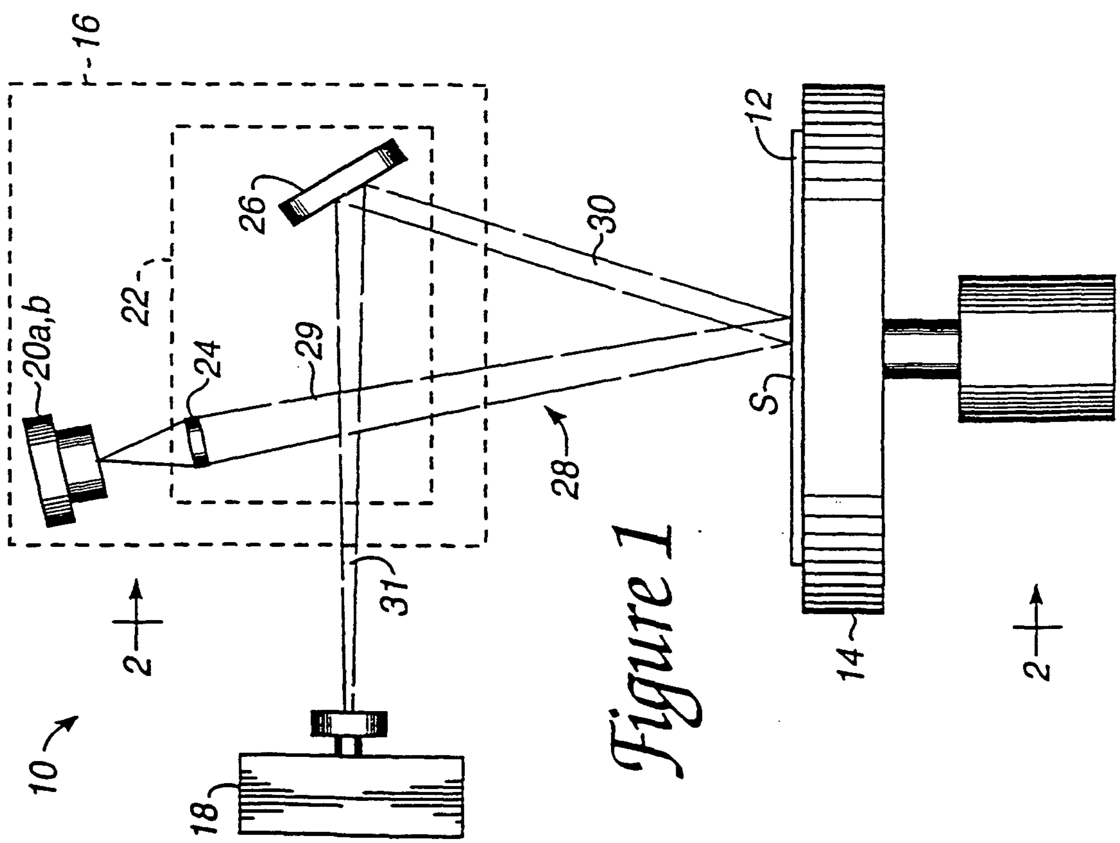


Figure 1

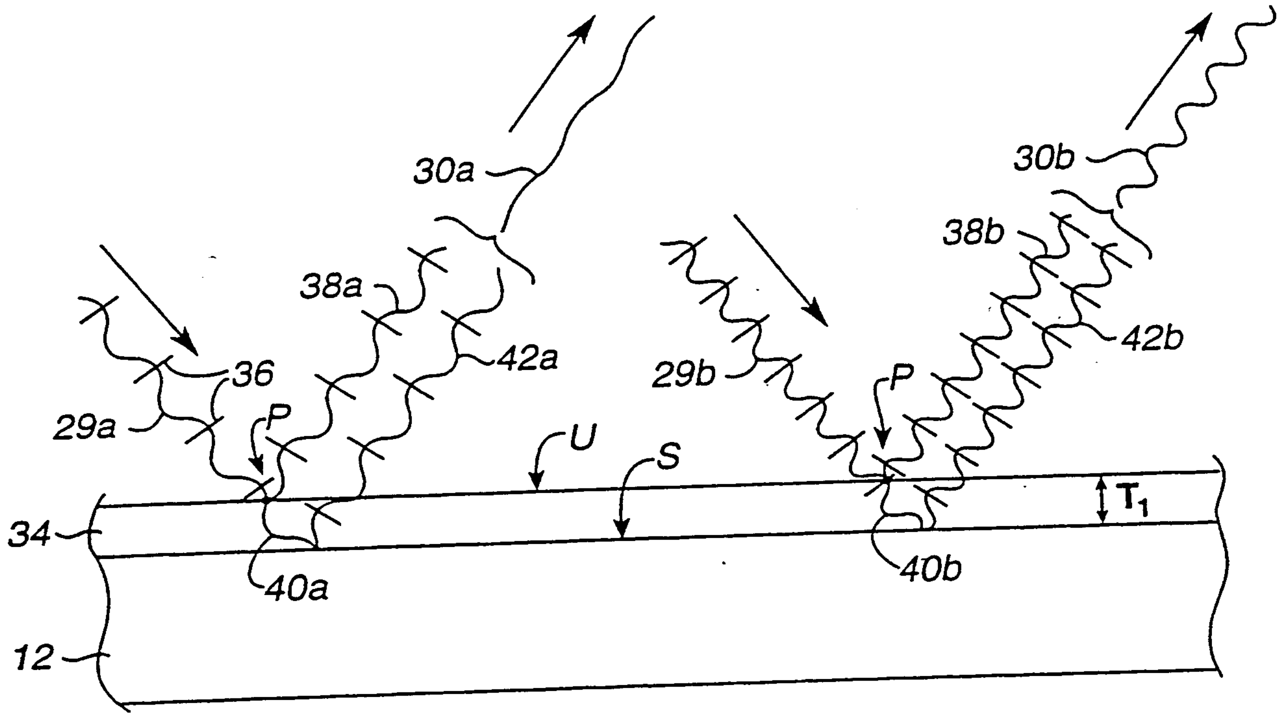


Figure 3

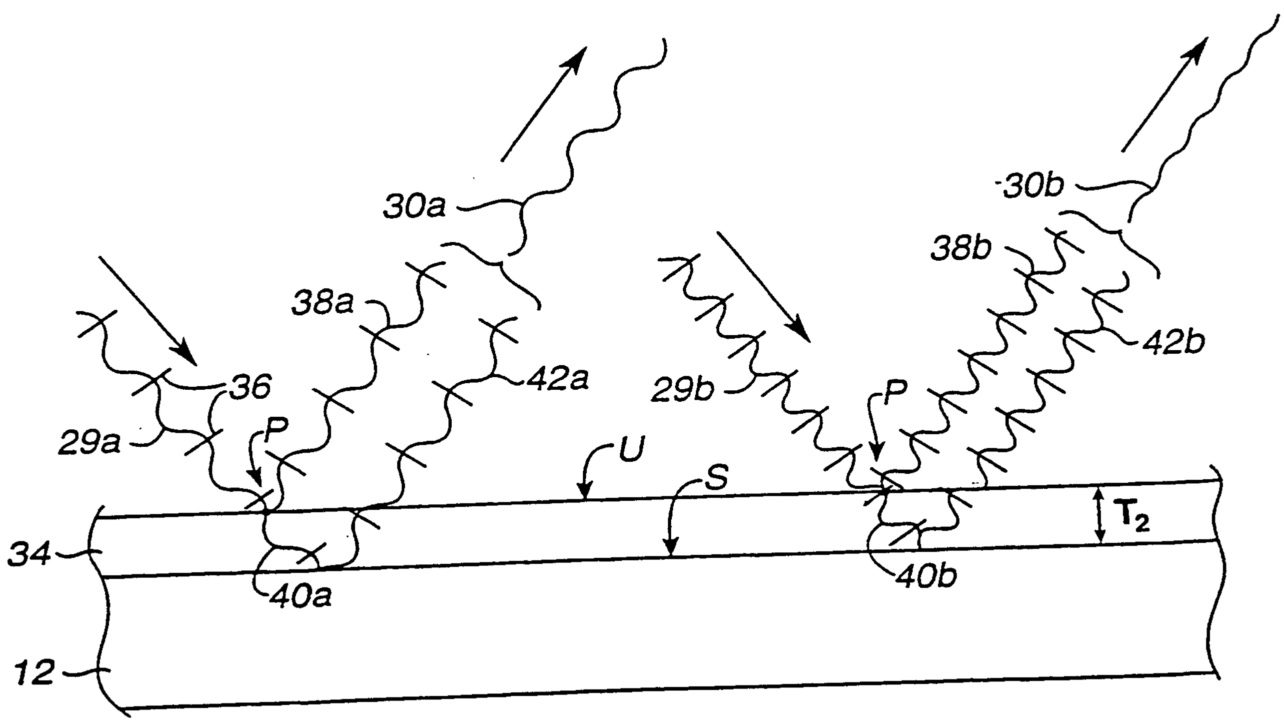


Figure 4

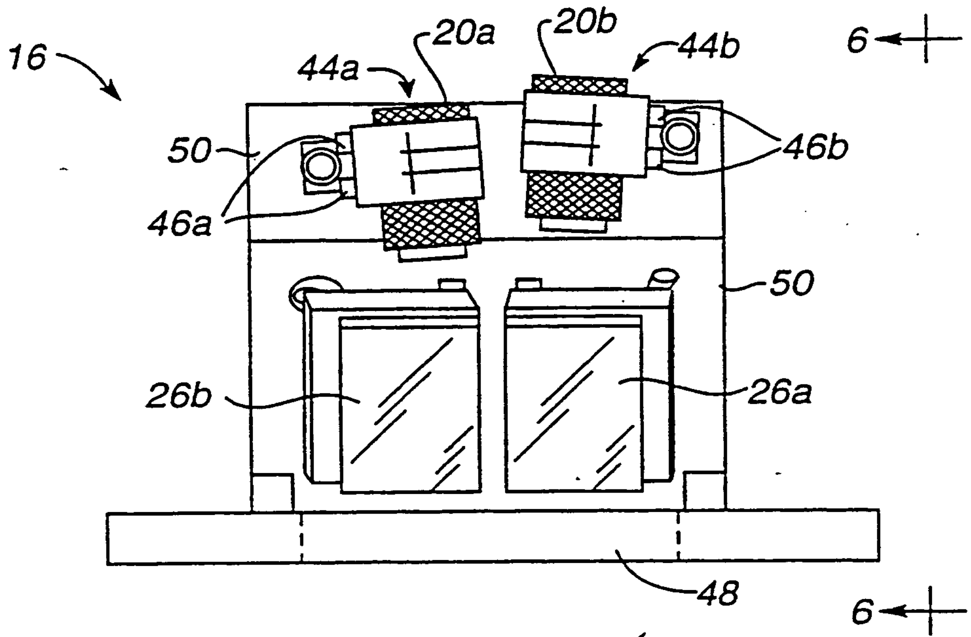


Figure 5

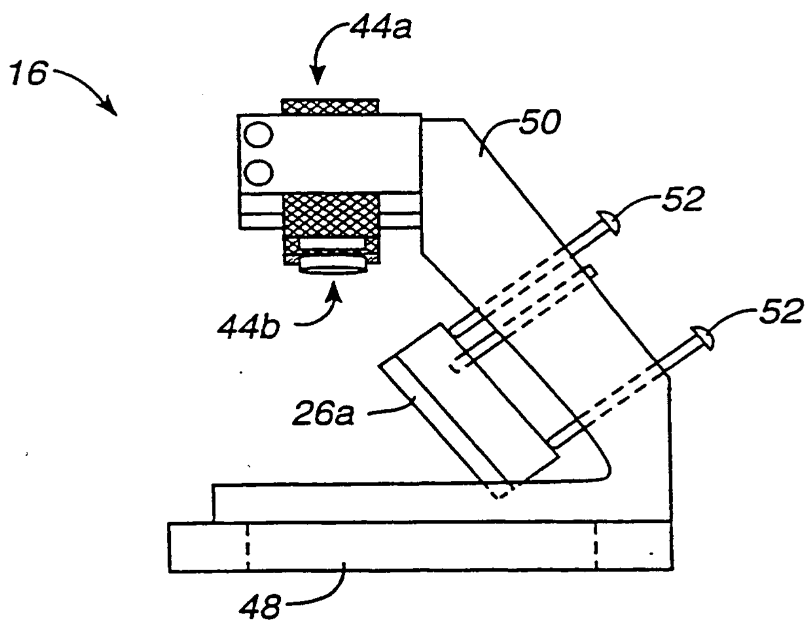


Figure 6

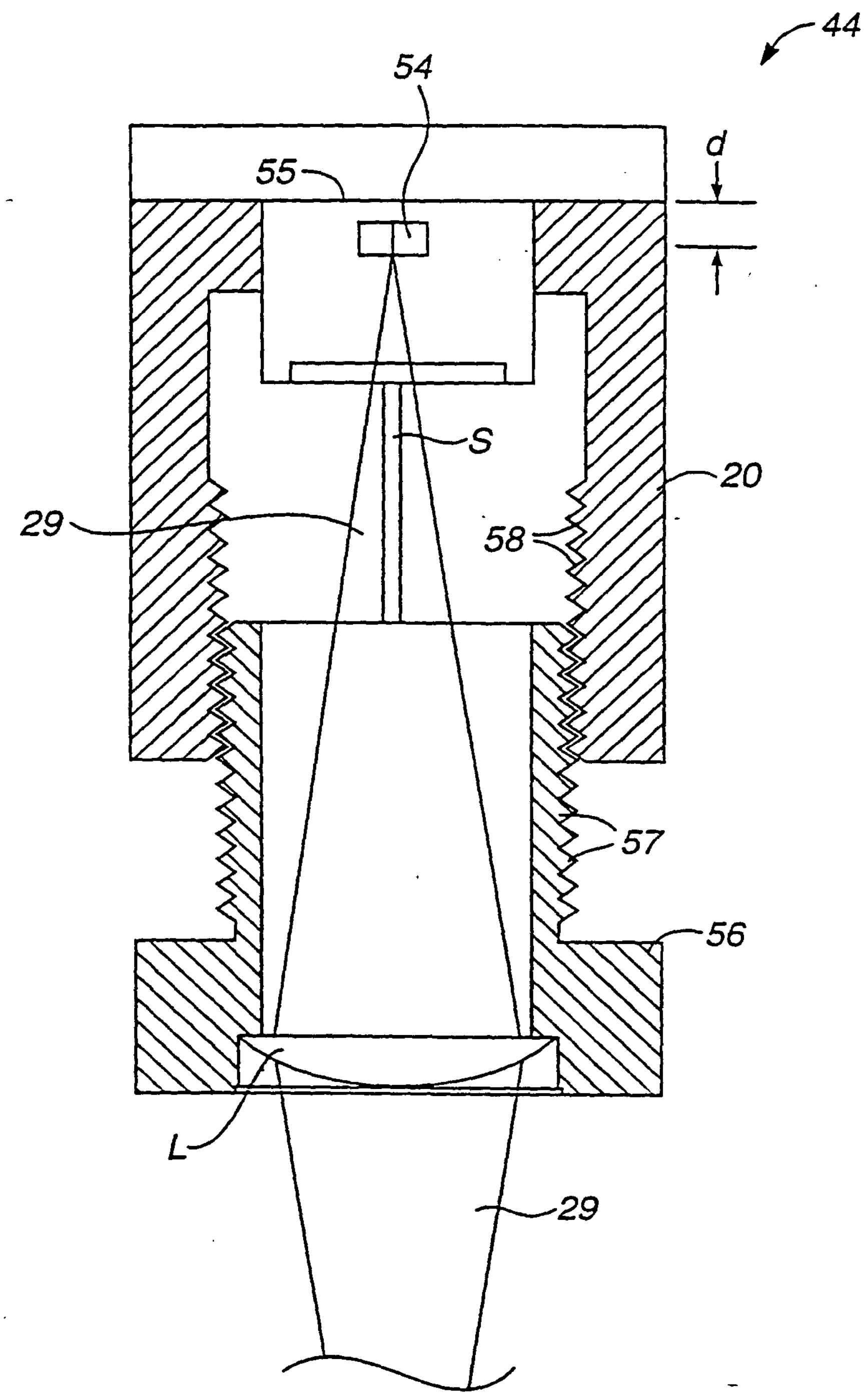


Figure 7

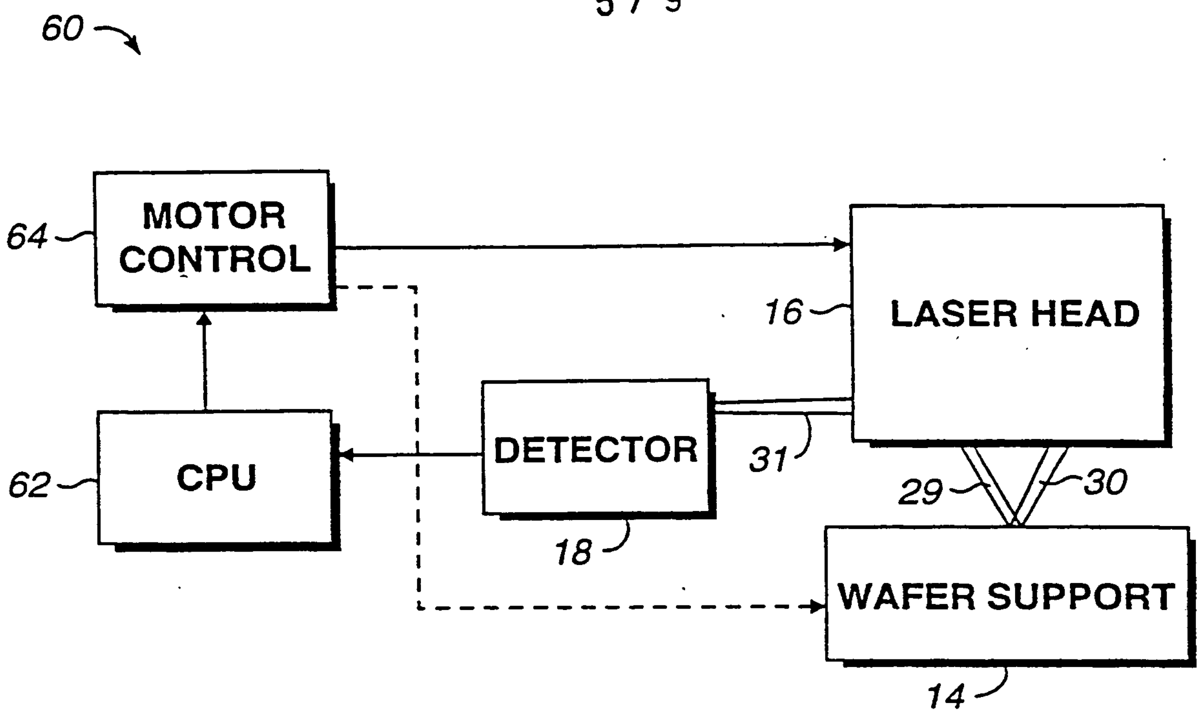


Figure 8a

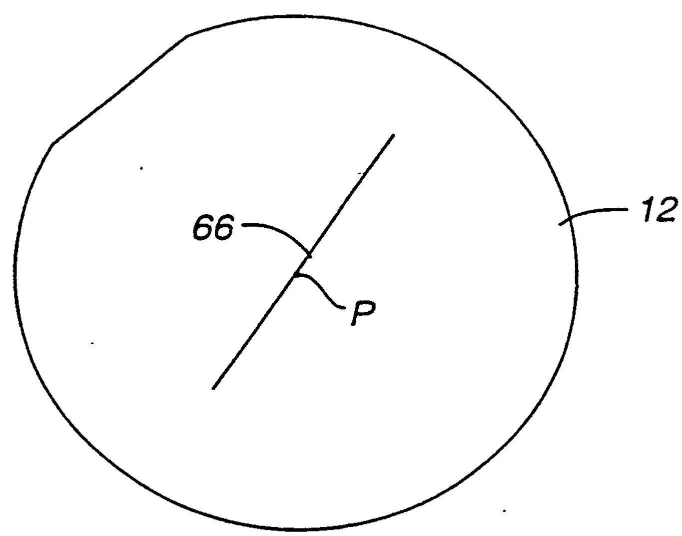


Figure 8b

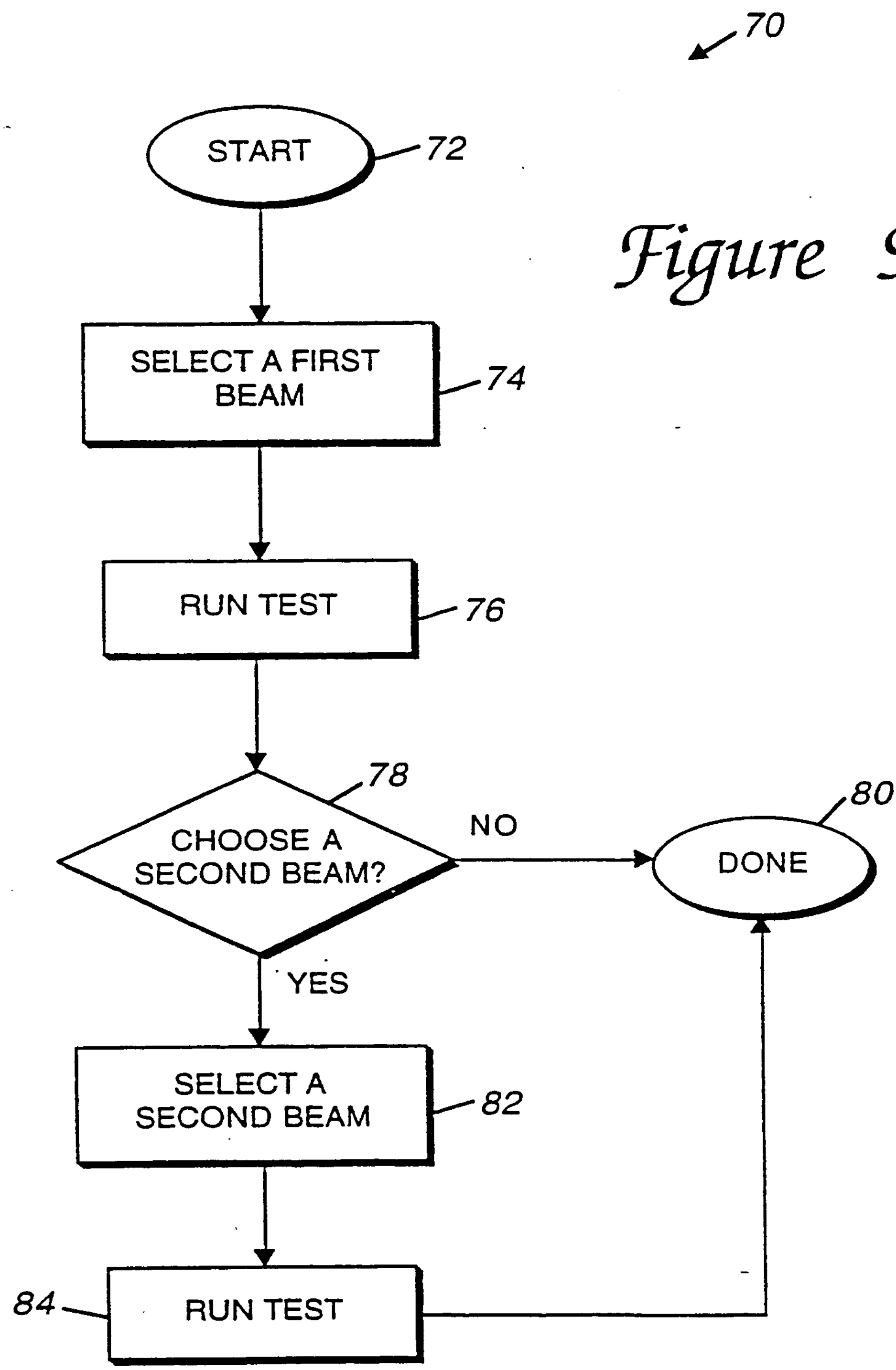

70
START
72
SELECT A FIRST BEAM
74
RUN TEST
76
78
CHOOSE A SECOND BEAM?
NO
80
DONE
YES
SELECT A SECOND BEAM
82
84
RUN TEST

Figure 9a

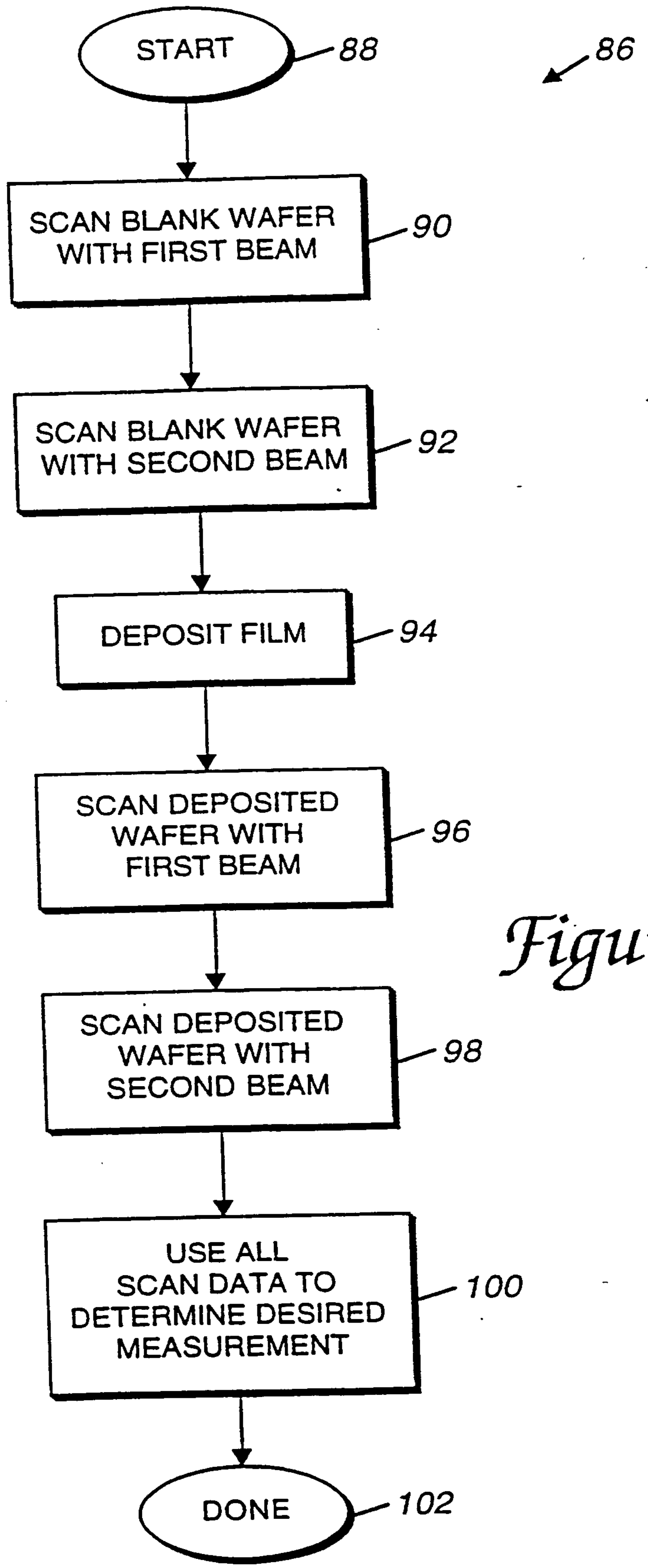

86
START
88
SCAN BLANK WAFER WITH FIRST BEAM
90
SCAN BLANK WAFER WITH SECOND BEAM
92
DEPOSIT FILM
94
SCAN DEPOSITED WAFER WITH FIRST BEAM
96
SCAN DEPOSITED WAFER WITH SECOND BEAM
98
USE ALL SCAN DATA TO DETERMINE DESIRED MEASUREMENT
100
DONE
102

Figure 9b

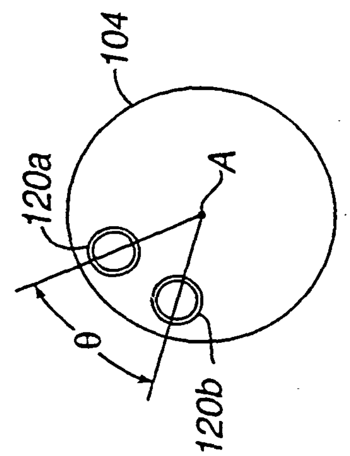


Figure 11

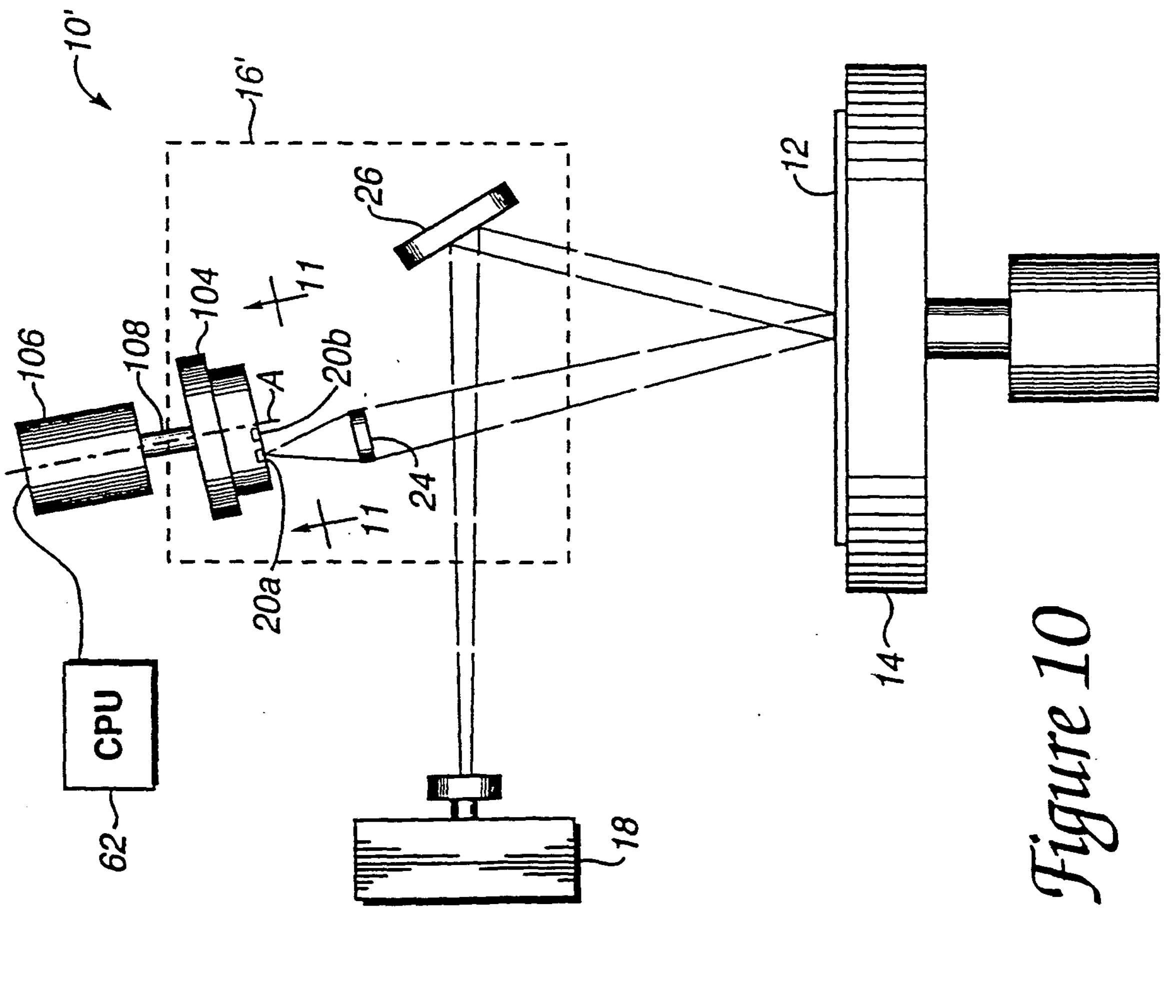


Figure 10

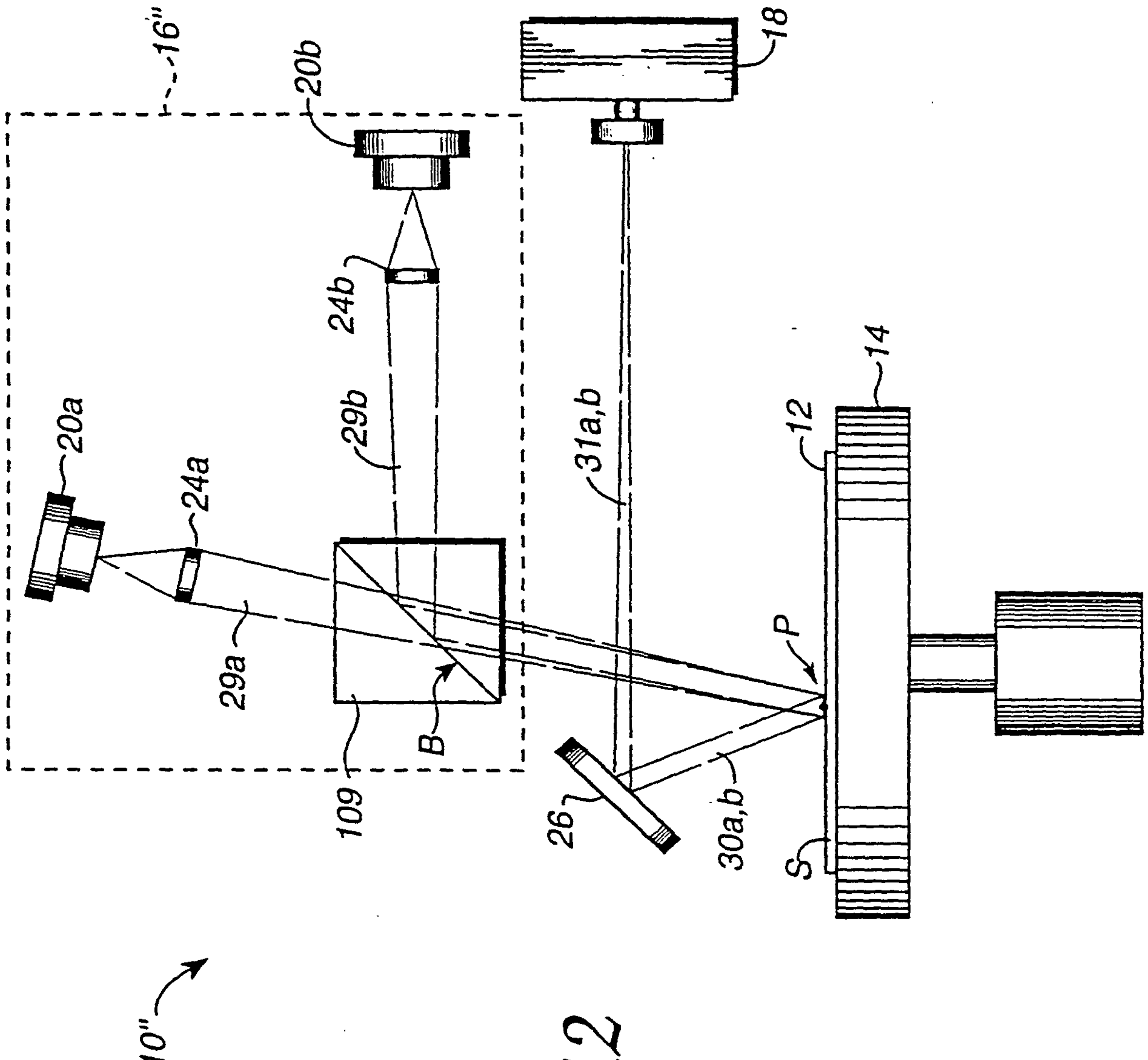


Figure 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/11871

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : G01N 21/86
US CL : 250/561
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US,A, 5,029,245 (KERANEN ET AL.) 02 JULY 1991 (See entire document)	1 -------- 2-21
Y	US,A, 4,432,239 (BYKOV) 21 FEBRUARY 1984 (See entire document)	13-21
A	US,A, 4,566,797 (KAFFKA ET AL.) 28 JANUARY 1986 (See entire document)	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 JANUARY 1995	11 JAN 1995

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	for QUE T. LE Telephone No. (703) 308-4830

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/11871

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment f additional search fees.

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

250/561, 560, 226, 201.5; 356/371, 376, 328, 420; 362/231, 230, 293; 372/23, 24, 26, 28; 219/121.76, 121.74; 369/44.21, 44.12, 44.37, 44.14

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s)1-21, drawn to a multi-frequency laser head, classified in class 250, subclass 561.
Group II, claim(s)22-34, drawn to a methode for measuring the curvature of a workpiece surface, classified in class 250, subclass 556.
The inventions listed as Groups I and II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Inventions II and I are related as process and apparatus for its practice. The inventions are distinct if it can be shown that either: (1) the process as claimed can be practiceed by another materially different apparatus or by hand, or (2) the apparatus as claimed can be used to practice another and materially different process. In this case the apparatus as claimed can be used to practice another and materially different process such as for detecting the presence/absence of an object. Moreover, the limitation of a beam with second wavelength as claimed in the invention of Group II is not required in the invention of Group I.